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# RADIOACTIVE SEDIMENTS IN THE TENNESSEE RIVER SYSTEM

J. M. Garner, Jr.,[1] and Oscar W. Kochtitzky,[2] A.M. ASCE

## SYNOPSIS

This paper discusses the development and use of instruments and techniques to survey gamma radioactivity in the sediments on the bottom of rivers and lakes. The equipment was used and refined during three summer surveys and has subsequently been applied to routine monitoring of bottom sediments in the lakes immediately downstream from Oak Ridge National Laboratory.

The "flounder", having a counting rate of less than 10 counts per second for uncontaminated sediment, readily detected increases in radioactivity in the bottom sediment resulting from liquid wastes released at Oak Ridge National Laboratory. The concentrations of radioactivity in the sediment which were presumed to have originated at Oak Ridge dropped off materially after the first 20 miles of the receiving reservoir and approached background levels at a distance of 100-150 miles. The survey, which extended from above Oak Ridge to the Ohio River almost 600 miles away, revealed several locations where sediment contained radioactivity of natural origin. This had resulted from the erosion of uranium bearing Chattanooga Shale.

No hazardous concentrations of radioactivity of either waste borne or natural origin were found.

## INTRODUCTION

The uranium pile and chemical separation plant at the Oak Ridge National Laboratory (originally Clinton Laboratories constructed in 1943 near the Clinch River in East Tennessee) were built to serve as a pilot plant for the Hanford Works in Washington. Since it was expected that these facilities would be operated for only one year, underground tanks were provided for storing the entire anticipated accumulation of radioactive liquid wastes.

The original facilities have continued in use long beyond the pilot plant period and have been increased to the extent that Oak Ridge National

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1. Health Physicist, Oak Ridge National Lab., Oak Ridge, Tenn.
2. Public Health Engr., Tennessee Valley Authority, Chattanooga, Tenn.

Laboratory is not only the principal production center for radioisotopes but is a rapidly expanding reactor research area. With the increase in volume of liquid wastes, there was a modification of the policy from "concentrate and contain" to one providing for the release of some radioactive liquid wastes by "diluting and dispersing" into the natural (and artificially impounded) surface waters of the region.

The maximum permissible concentration (MPC) of radioisotopes of unknown identity in drinking water which could be used throughout one's lifetime without resulting in provable harm(1) is $1 \times 10^{-7}$ microcuries per cubic centimeter.[3] Releases to the Clinch River are regulated so that the resultant average concentration is kept below this MPC. To facilitate this dispersal there have been constructed a 1,600,000-gallon settling basin for temporary holdup and a 44-acre lake(2) for retention of the wastes before release to the Clinch River. The discharge of radioisotopes into White Oak Creek is limited to 35 curies per week.(3) In terms of the units ordinarily used in water works practice this quantity is extremely small. For example, if radiostrontium, $Sr^{89}$, were discharged at this rate and uniformly dispersed into a stream flowing 3,500 cubic feet per second, the corresponding concentration would be $21 \times 10^{-12}$ parts per million and it would take 433 years to dispose of one ounce of strontium, if decay were not taken into account.

## Purpose

Radioactive materials are known to be absorbed by biological organisms, adsorbed on clay particles occurring as turbidity in streams, or precipitated by other physical or chemical means thus resulting in the accumulation of radioactive substances in the sediment. The purpose of the surveys was to determine: the extent of dispersion of radioactive materials in river sediment; the level of radiation encountered and consequent external hazard to humans; the amount of present accumulations and predicted future accumulations; the capacity of the TVA system of lakes as a place of permanent disposal; and the validity of the present policy of discharging to nature some of the radioactive wastes.

## Procedure

### Instrumentation

Due to the short range of alpha and beta particles in water and in mud any potential external hazard that might be encountered in the sediment would most likely be due to gamma emitters. The instrument, called the "flounder", was developed and used in the surveys for measuring gamma radiation in the water and at the surface of the mud.

The flounder is a gamma detector containing twelve thin-wall Geiger-Mueller tubes in a water proof housing 15-1/2" x 15-1/2" x 1-1/2". Figure 1 shows two views of the flounder. The one on the right shows the method of suspension by a yoke clamped to the rubber covered cable. On the left the 1/4" lucite side (treated with aquadag for exclusion of light) is removed to

3. One microcurie is $10^{-6}$ curies. One curie is the quantity of any radioactive nuclide in which the number of disintegrations per second is $3.7 \times 10^{10}$.

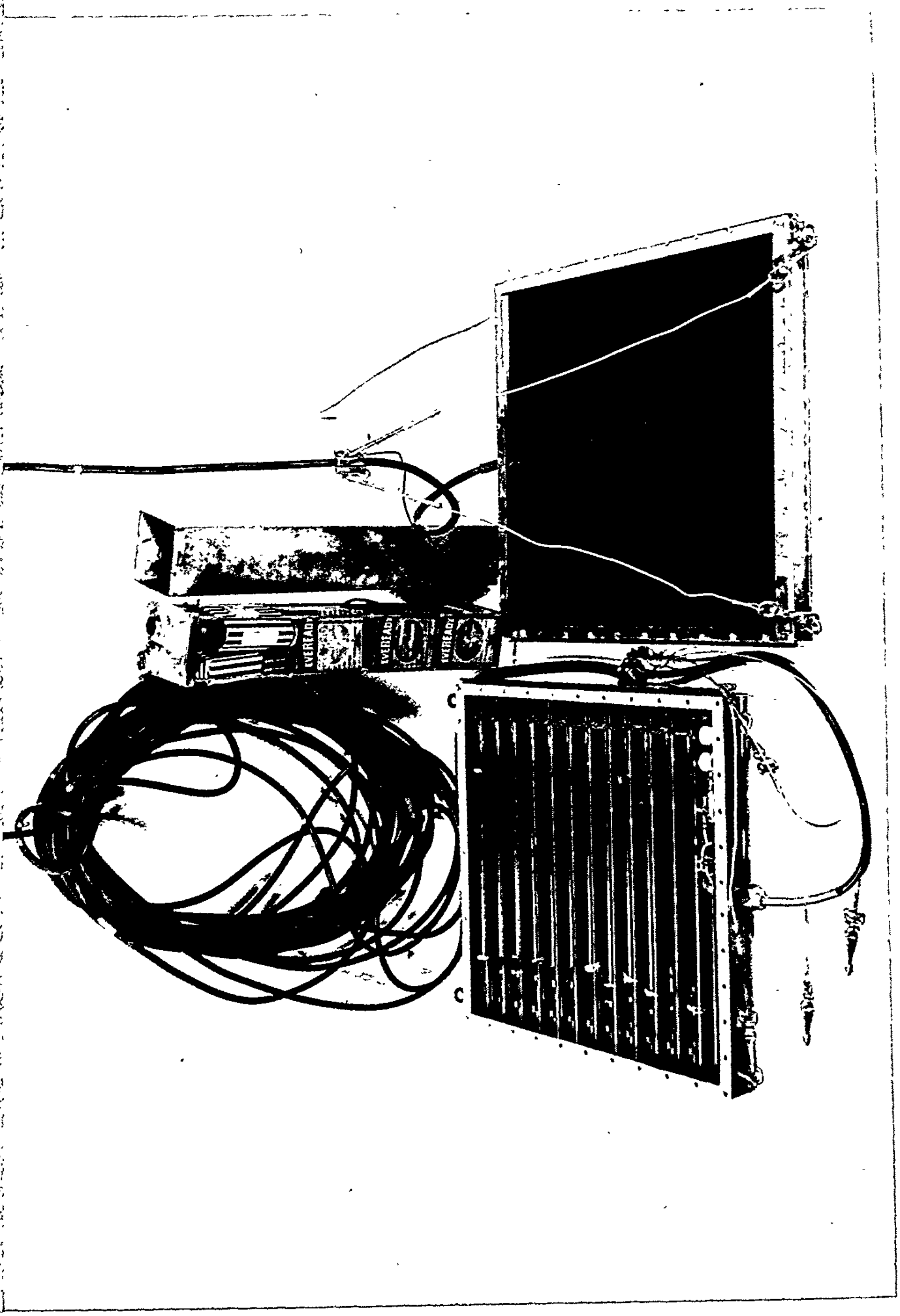


FIG. 1

reveal the twelve GM tubes and the compact electronic circuitry enclosed by the case. The five conductor rubber covered cable, marked with tape for determining depth, and the batteries for high voltage (900 v.) to the GM tubes are shown.

### Radioactive Assay of Mud Samples

For beta counting, 0.64 gram (dry weight) was slurried on a shallow stainless steel dish over an area of 6-3/4 square centimeters, dried under heat lamps and covered with Scotch tape. The dishes were supported on the first shelf beneath end window GM tubes and the sample counted for at least twenty minutes. A solution of thallium ($Tl^{204}$) known to undergo $10^5$ disintegrations per minute was mixed with uncontaminated mud, treated in the same manner as the mud sample, and used as a comparison standard.

For gamma counting, 2 ml volumetric flasks were filled with dried mud (2.1 gm), placed within the cavity of a sodium iodide scintillation counter and counted for ten minutes. A two-ml sample of Cobalt ($Co^{60}$) known to undergo $2.11 \times 10^5$ disintegrations per minute was counted for comparison. Since $Co^{60}$ emits two gamma rays per disintegration, the counting efficiency of the mud sample was taken to be one-half the $Co^{60}$ efficiency.

The beta counting efficiency was found to be 5.0% in terms of $Tl^{204}$ (maximum beta energy 0.78 Mev), the gamma counting efficiency to be 16.5% in terms of 1/2 $Co^{60}$ (average gamma energy 1.25 Mev). For converting counting rate into micro-microcuries per gram the formula

$$\mu\mu c/g = \frac{\text{counts per minute}}{\text{counting efficiency}} \times \frac{1}{\text{grams of sample}} \times \frac{1}{2.22 \text{ disintegrations per minute per micro-microcurie}}$$

was used.

There is no reason to believe that the radiations from the radioisotopes in the mud are of these energies. However, activity was reported in terms of these standards (a) to obtain an order of magnitude and (b) to have a simple standard method of reporting activity of unknown energy.

### 1951 Reconnaissance

Observations were made from July to September in the Clinch River below the point at which White Oak Creek enters and in the TVA reservoirs to about the midpoint of Guntersville Reservoir, a distance of over 200 miles (see Fig. 2).

A seventeen-foot outboard motorboat was utilized in this survey. The survey equipment consisted of the flounder, batteries and preamplifier, counting rate meter, continuous chart recorder, a gasoline operated motor-generator set with voltage regulator and auxiliary equipment, and the sampling equipment and containers for collecting sediment samples.

Using TVA navigation charts the approximate locations of sampling stations on the river or lake were determined. At first the location of a station in the transverse section was approximated visually. Later the distance from shore was judged by measuring the time required to traverse the distance at top speed of the boat. The accuracy of this approximation was dependent on the direction and velocity of the wind, the load in the boat, and the performance of the motor and in general was found to be acceptable.

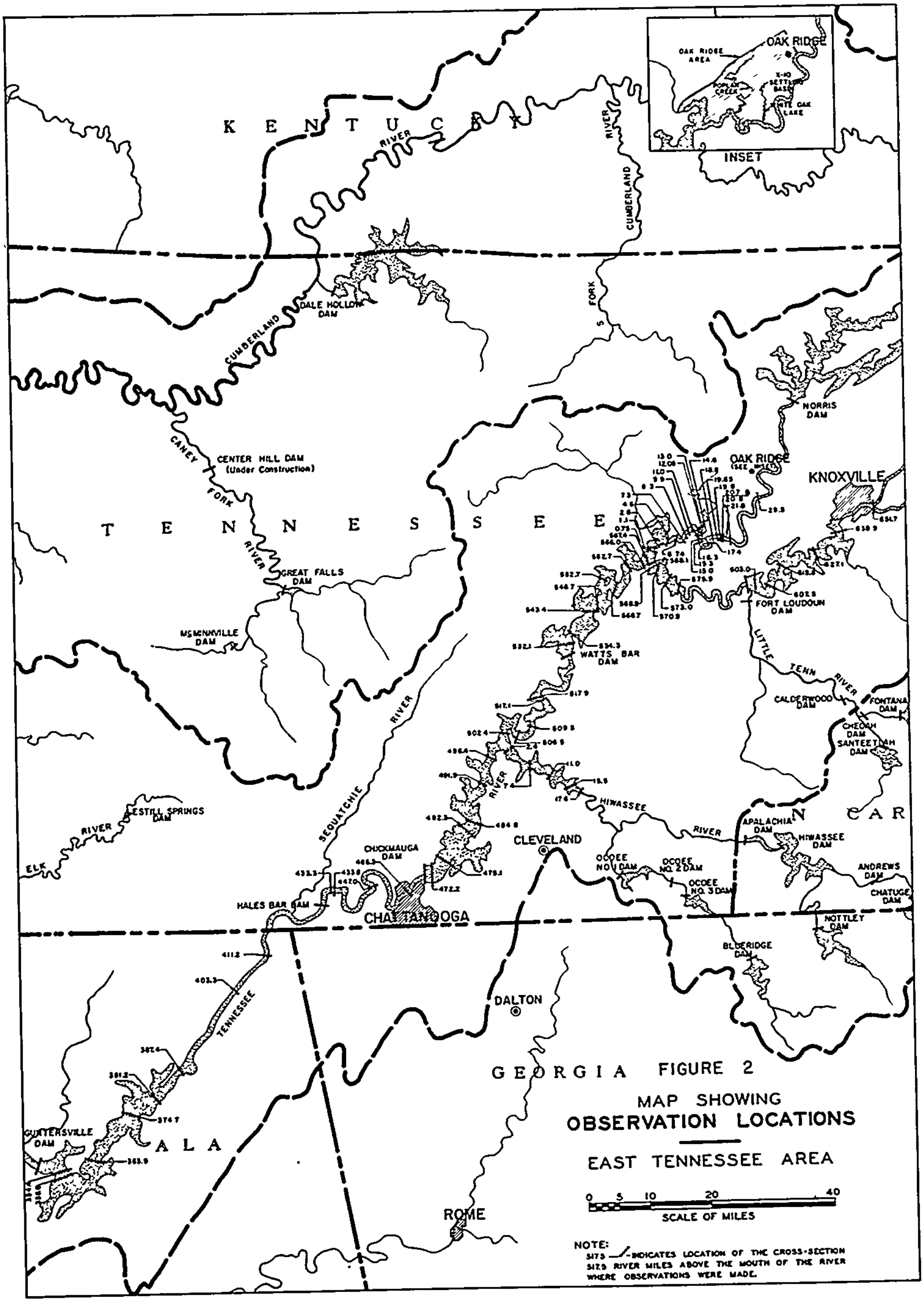


FIGURE 2

MAP SHOWING
**OBSERVATION LOCATIONS**

EAST TENNESSEE AREA

The flounder was lowered and allowed to come gently to rest flat on the bottom. If the bottom mud was stirred up and some settled on top of the flounder, it would cause higher counting rates thus interfering with the determination. After the instrument counting rate reached equilibrium the recorder was run for at least three minutes. Pertinent information, such as location, time, and depth was entered on the chart beside the plotted record of the counting rate. Depending on the width of the river or lake and the relative proportion of shallow and deep water in the transverse section, three to a dozen or more readings were necessary to obtain representative data at each station. The distance between stations averaged two miles in the Clinch River and nearly ten miles in the lakes below the mouth of the Clinch River. Observations were also made in the principal tributaries and in some cases extended as far as 19 miles from the main stem of the reservoir in order to obtain readings at locations beyond the effects of impoundment.

Sufficient readings were made at different locations and different depths with the flounder suspended in a vertical position to establish the "water background" counting rate at any depth. These observations were made at least two yards above the bottom in order to avoid the influence of radiation from bottom deposits. Water background measurements provided data for correcting the counting rates observed in the survey for residual cosmic radiation intensity and natural radioactive content of the water. Measurements of "mud background" were made in several streams and lakes where no artificially introduced radioactivity would be encountered. Mud background was used only for comparison with the plotted data.

## 1952 Survey

The reconnaissance during 1951 provided experience in the use of the equipment and led to some modifications of equipment and technique which resulted in facilitating the collection and use of data. Because of the greater distances to be covered and the hazards inherent in using small heavily loaded boats in large open bodies of water, a 22-foot inboard motor launch was used. The field party consisted of three and sometimes four men. The survey was begun at the mouth of the Tennessee River in June and continued upstream to Oak Ridge. The field work, including background measurements in several reservoirs on tributaries (Norris, Fontana, Hiwassee and other Reservoirs) was completed in September.

In addition to navigation charts, this party was provided with the locations of silt ranges and the cross-sections of the stream at the silt ranges. Practically all observations were made on silt ranges. The transverse location was approximated by traveling a given number of seconds along the range at a known engine speed and was checked by comparing the depth obtained by sounding to the depth shown on the plotted cross-section. This method of checking location was especially valuable in the larger lakes where wind and wave action had considerable influence on boat speed (when compared to engine speed).

The pulses from the flounder instrument used in this survey were fed into a scaler instead of into the counting rate meter used the preceding year. Counts were taken for five minutes or to the nearest minute after 30 scalers (scale of 64) were recorded, whichever came first. Measurements were taken for some distance up most of the principal tributaries to check the possibility of a variable "mud background."

1953 Survey

A less extensive survey than that in the preceding year was carried out during August and September using the outboard motor boat which had been used in 1951. In the Clinch River a tag line fastened across the stream was used for determining transverse locations. More observations (at 50-foot intervals) were made in the cross-sections than were made in the same cross-sections during preceding years, but fewer cross-sections were investigated. Only three cross-sections in Watts Bar Reservoir (other than the Clinch River embayment) and two in Chickamauga were studied.

A battery powered scaler was substituted for the motor-generator set and the scaler previously used. This resulted in considerable reduction in weight and crowding in the boat.

## Presentation of Data

The total data assembled in these studies are too voluminous to include in this report. The averages of counting rates for the cross-sections were obtained by weighting each observation in the transverse section by the proportion of the total cross-sectional width of which it was representative. When a large number of readings were taken at a cross-section, each observation was considered to be representative of that part of the cross-section extending halfway to the next observation point in each direction. When fewer readings were taken additional criteria were necessary. In this case both depth and slope of bottom (as visually analyzed on the plotted cross-section) were used in deciding which portion or portions of the cross-section should be represented by individual observations, grouping those portions having similar configuration. These averages have been plotted in Figs. 3 and 4 which show the averages at the surface of the bottom sediment (after correcting for "water background") which were observed in 1951, 1952, and 1953. Figure 5 shows a comparison of the highest counting rates observed. Figure 6 is intended to compare the total accumulation of radioactive sediments along the bottom of the Clinch River; on it are plotted the quantities obtained by multiplying the average counting rate by the width of the river or lake at each station.

Efforts to identify the particular gamma emitters discharged and to determine the ratio of the rate of gamma-ray emission to total disintegration rate of the wastes discharged from White Oak Creek have been handicapped by the low concentrations of radioisotopes. A review of the available records(5) in an attempt to determine the beta-gamma ratio in the water has revealed inconsistencies which cannot be explained. A comparison of the beta-gamma ratio found in mud samples is given in Table I which also gives the relative counting rate of samples from various locations.

## Discussion

### Average Counting Rate

Figure 7 shows a map of the Tennessee Valley with all the main river reservoirs. It would be impractical to indicate on a map of this size all the points at which measurements were taken or to include a map large enough to show all the points. This map will help the reader to visualize the locations relative to the various dams and provides relative geographical positions.

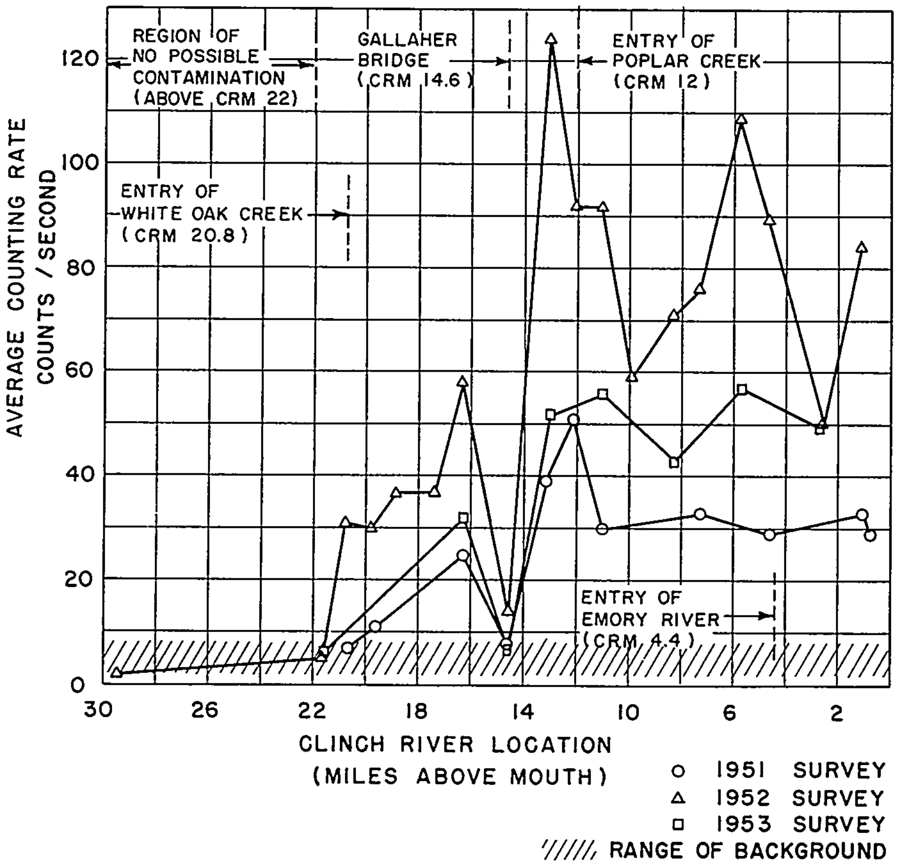


FIGURE 3

CLINCH RIVER SEDIMENTS

AVERAGE RADIATION COUNTING RATE AT MUD SURFACE

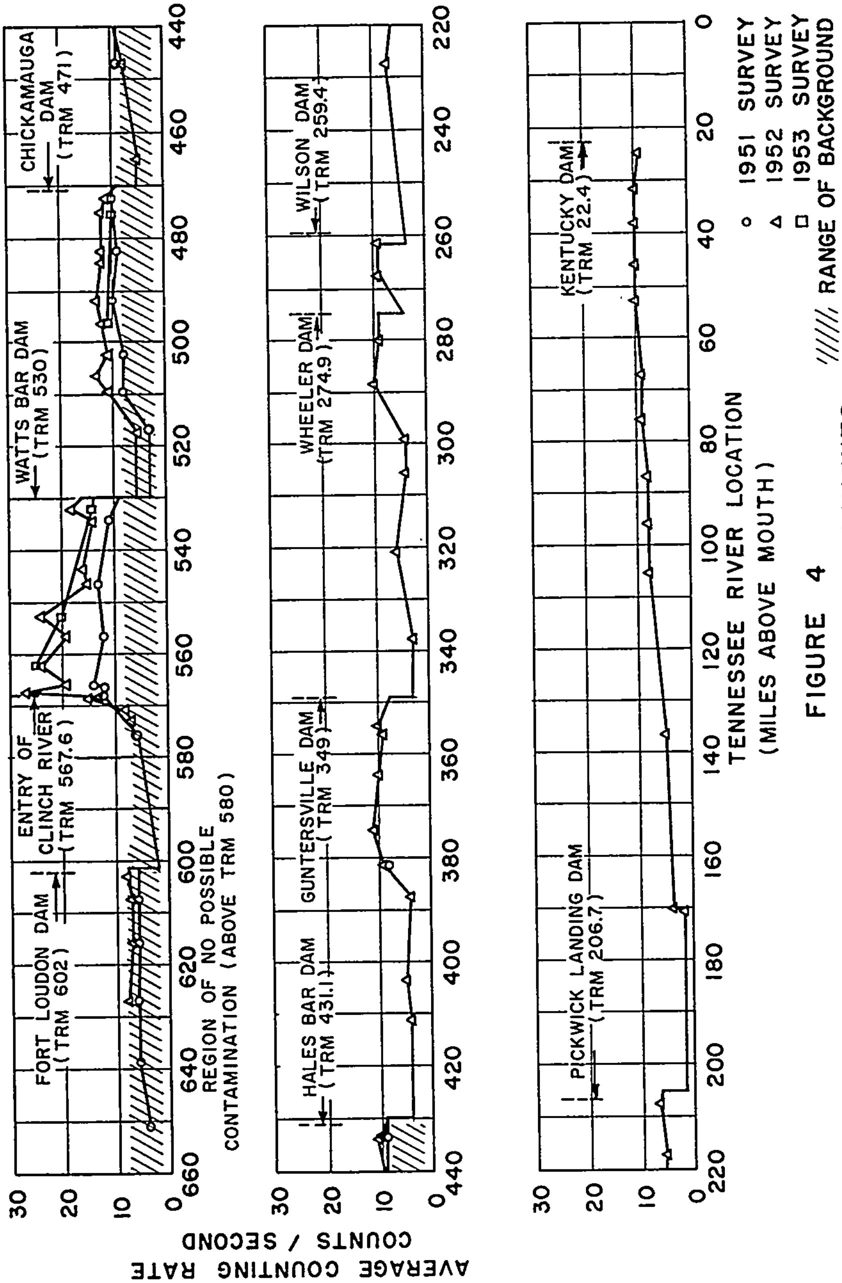


FIGURE 4

TENNESSEE RIVER SEDIMENTS

AVERAGE RADIATION COUNTING RATE AT MUD SURFACE

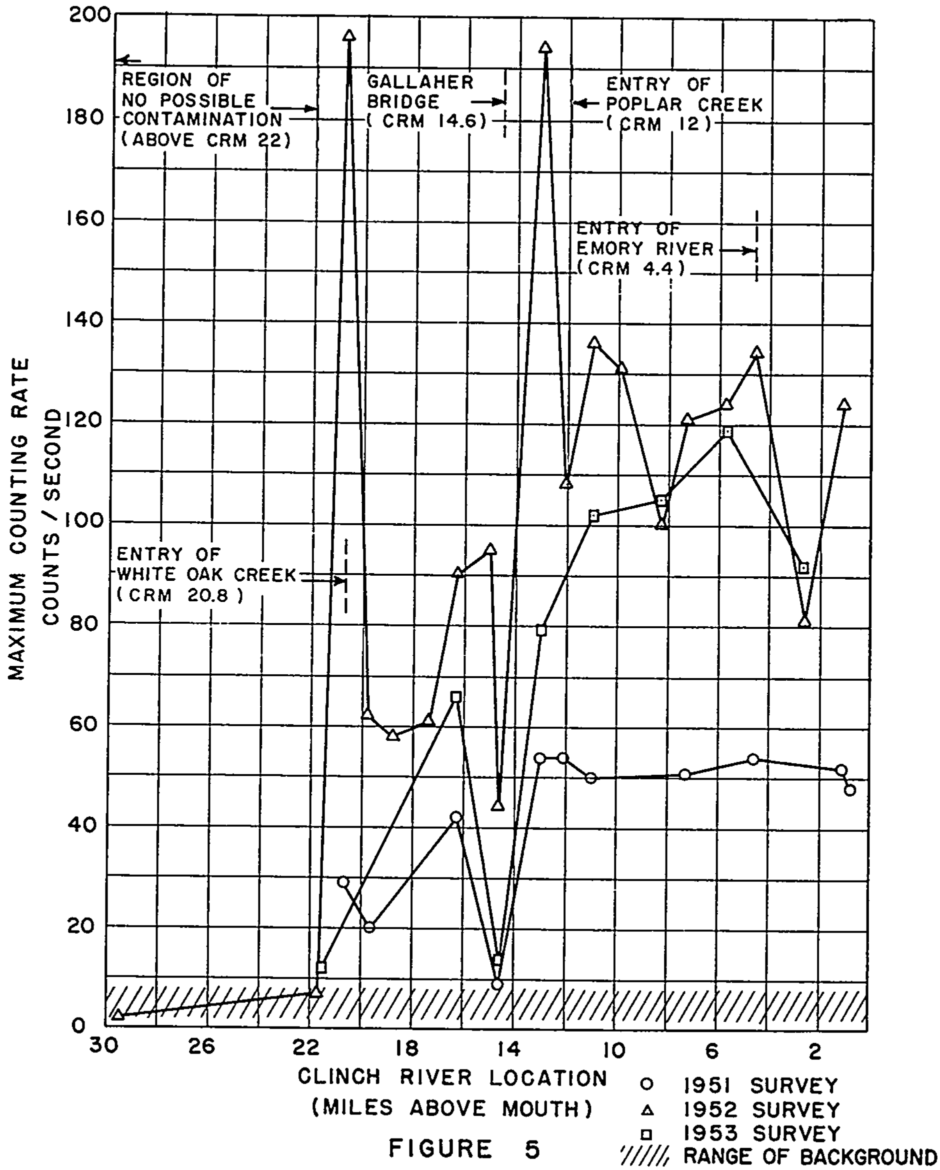


FIGURE 5

CLINCH RIVER SEDIMENTS

MAXIMUM RADIATION COUNTING RATE AT MUD SURFACE

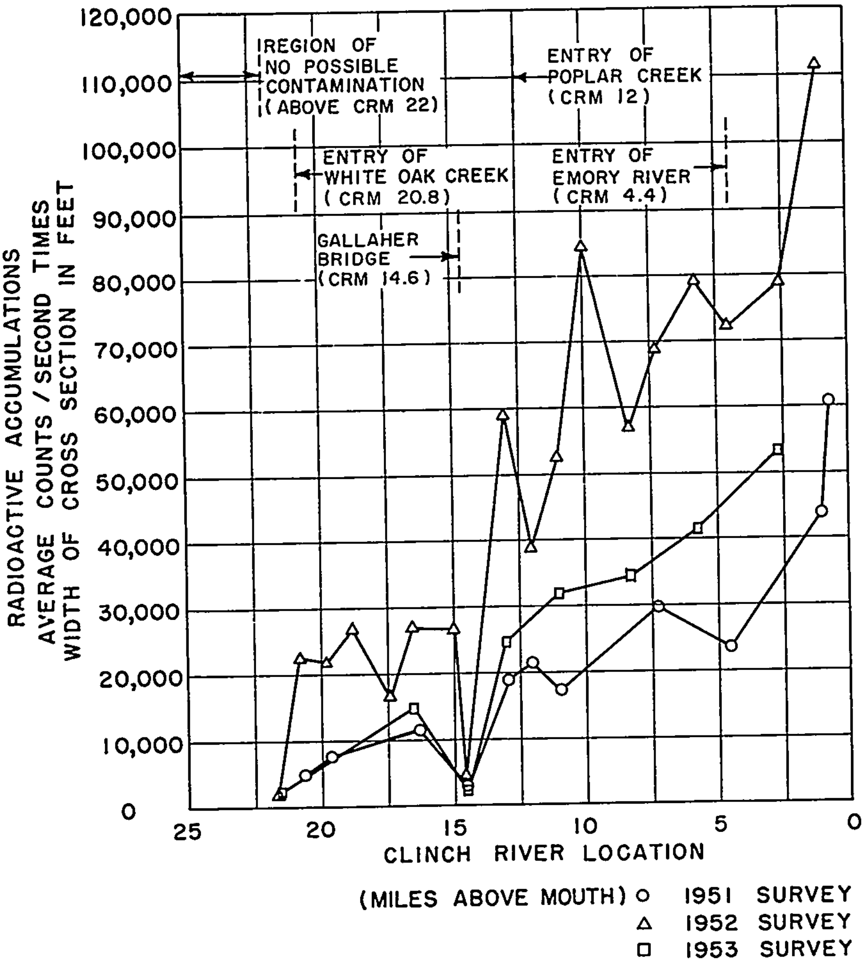


FIGURE 6

CLINCH RIVER SEDIMENTS

CALCULATED RADIOACTIVE ACCUMULATIONS

Table I
Radioassay of Mud Samples

| Sample No.* | Location | Beta Counting Rate cpm | Gamma Counting Rate cpm | Beta Activity $\mu\mu c/g(Tl^{204})$ | Beta-Gamma Ratio | Gamma Activity $\mu\mu c/g(Co^{60})$ | Net c/m Flounder Reading (Corrected for $H_2O$ Background) | Date Counted |
|---|---|---|---|---|---|---|---|---|
| 2A | ORM 937.3 | 5.4 | 14 | 80 | 3.2 | 20 | 748 | Gamma: 10/17-23/52 |
| 2B | (below Tenn.R) | 5.5 | 25 | 80 | | 30 | | " |
| 3 | ORM 930.2 (above Tenn.R) | 3.1 | 14 | 40 | 2 | 20 | 1866 | " |
| 4 | ORM 928.5 (below Cumb.) | 7.6 | 48 | 110 | 1.8 | 60 | 6184 | " |
| 1A | TRM 45.8 | 4.2 ± 1.4 | 14 ± 6 | 60 ± 20 | 3 | 20 ± 10 | 684 ± 23 | Beta: 10/17-18/52 |
| 1B | | 4.3 | 12 | 60 | | 20 | | Gamma: 10/17-23/52 |
| 5A | TRM 207.3 | 4.2 | 17 | 60 | 2.8 | 20 | 455 | " |
| 5B | | 3.8 | 16 | 50 | | 20 | | " |
| 7A | Wilson 4 (mi. 267.4 4000 ft.) | 5.6 | 27 | 80 | 2.4 | 40 | 525 | " |
| 7B | | 6.3 | 19 | 90 | | 30 | | " |
| 8A | Wheeler 8 | 6.6 | 32 | 90 | 2.7 | 40 | 594 | " |
| 8B | (TRM 280.0) | 7.2 | 21 | 100 | | 30 | | " |
| 9A | Guntersville | 6.6 | 28 | 90 | 2.4 | 40 | 851 | " |
| 9B | (TRM 374.7) | 7.1 | 30 | 100 | | 40 | | " |
| 13A | TRM 552.7 | 11.1 | 69 | 160 | 1.9 | 90 | 1956 | " |
| 13B | | 12.5 | 76 | 180 | | 100 | | " |
| 14 | TRM 567.4 | 12.3 | 101 | 170 | 1.3 | 130 | 3219 | " |
| 15 | CRM 9.9 | 23.7 | 219 | 330 | 1.1 | 290 | 7865 | " |
| 16 | CRM 13.0 | 26.8 | 260 | 380 | 1.1 | 340 | 11615 | " |
| 18 | Big Creek | 4.4 | 21 | 60 | 2.0 | 30 | | 11/7/52 |
| 21 | Powell R. | 5.1 | 9 | 70 | 7.0 | 10 | | " |
| 23 | Clinch R. | 2.8 | 13 | 40 | 2.0 | 20 | | " |
| 24 | Hiwassee R. | 9.4 | 19 | 130 | 6.5 | 20 | | " |
| 25 | Ocoee R. | 7.4 | 17 | 100 | 5.0 | 20 | | " |
| 26 | Santeetlah | 4.1 | 8 | 60 | 6.0 | 10 | | " |
| Chatt.Shale/Jackson Co. | | 27.4 | 86 | 370 | 3.3 | 113 | | |

Note: For Samples 3 and 4 taken from the Ohio River, the energy of the radiation and consequently the counting efficiency in mud was much different from Tennessee River samples. Statistical variation, shown only for Sample 1A, indicates magnitude of probable errors.

* A and B denote duplicate assays for the same sample.

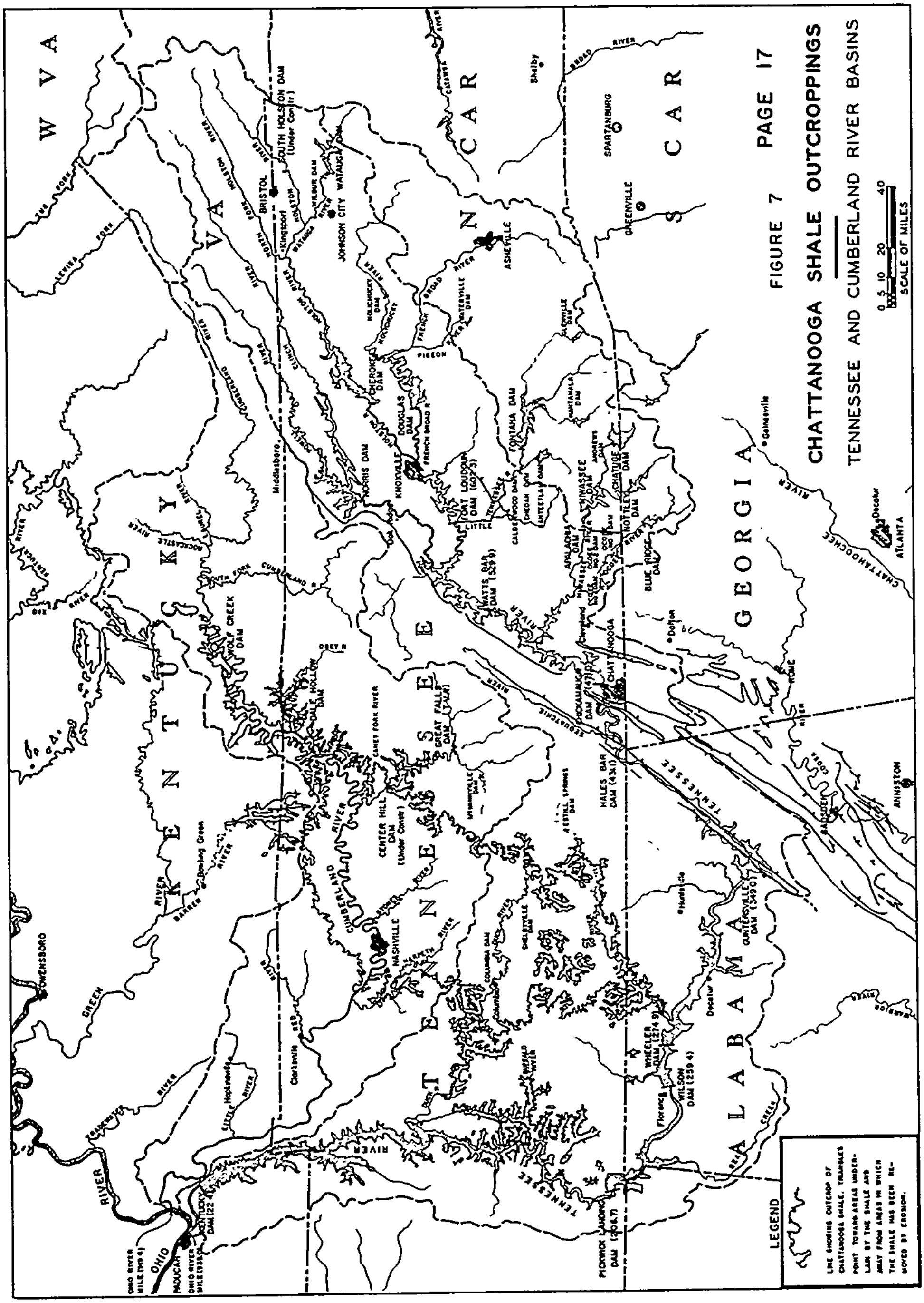


FIGURE 7 PAGE 17
CHATTANOOGA SHALE OUTCROPPINGS
TENNESSEE AND CUMBERLAND RIVER BASINS

The Cumberland River Valley, just north of the Tennessee Valley, is also included. The general location of outcroppings of Chattanooga Shale has been indicated.[6,7]

Wastes which have been stored in White Oak Lake until discharge enter the Clinch River arm of Watts Bar Reservoir at Clinch River Mile 20.8. While backwater from Watts Bar Dam extends 28 miles up the Clinch River at times of full pool, it barely extends to the mouth of White Oak Creek at minimum pool level (October-April). Thus, for much of the year considerable velocity occurs in the Clinch River at the mouth of White Oak Creek. This velocity tends to scour the sediment which might otherwise be deposited at this point. Referring to Fig. 3 a gradual buildup below Mile 20.8 is seen which is interrupted by scour at Mile 14.6. At this point the channel is restricted by the Gallaher Ferry bridge and the water velocity prevents the deposition of bottom sediment. The increase in counting rate continues downstream to Mile 12 in 1951, Mile 13 in 1952, and Mile 11 in 1953. From there to the mouth of the Clinch River the counting rate was relatively constant in 1951 and 1953 and of the same order of magnitude, though not quite so constant, in 1952. A phenomenon of deep reservoirs known as thermal stratification[8,9] may be responsible for this deposition pattern. During the summer the water released at Norris Dam is considerably colder than the water on the surface of Watts Bar Reservoir. Due to density differences this cold water "ducks under" the warm water on the surface and flows as a bottom stratum. It can readily be seen that the cold water will comprise practically all the water moving downstream in the Clinch River embayment and the velocity and consequent carrying capacity will vary accordingly.

The counting rates observed in 1952 were approximately twice those measured in 1951 and 1953. Referring to monitoring data[5] there seems to be some indication of a shift in the relative predominance of various radioisotopes in the wastes before the 1952 survey. This apparent trend cannot tell the whole story since the elapsed time between sample collection and radiochemical analysis (in the routine monitoring program) would permit the reduction by decay of such short lived isotopes as barium. While the barium in the various component parts of the composite sample might have passed through one to three half-lives, barium still accounted for as much as 20 percent of the identified beta radioactivity during one month. Freshly discharged wastes of short half-life, such as barium, might have been detected in the stream bed by the flounder and still might decay to the vanishing point during the six weeks required for collection and analysis of the monthly composite sample. It would have decayed below detectable concentration by the time of the 1953 survey.

During the summer (June-September) of 1952, stream flow in the Clinch River[10] was less than 60 percent as great as the flow during the corresponding period in 1951 or 1953. With low flow the stream's capacity to transport suspended matter is reduced. Consequently, a larger portion of the transported silt was deposited in the Clinch River embayment during 1952 than during 1953.

On Fig. 3 it is seen that the curve for radiation counting rate in the Clinch River sediment during 1952 is approximately twice as high as that for 1953. On the other hand in Watts Bar Reservoir proper (Fig. 4) there is little difference observed between the two years.

By analysis it was determined that the naturally occurring radioactive isotopes of uranium, thorium, and potassium accounted for only 25 percent of the radioisotopes in the Clinch River mud (Mile 13) and 43 percent in the Tennessee River sample (Mile 567.4). The remainder of the radioactivity was from fission products of which the most prominent were ruthenium, cesium, and cerium.

An interesting situation was encountered during 1952 in a stretch of the Clinch River between Mile 4.4 where the Emory River enters and Mile 0.0 where the Clinch flows into the Tennessee River. The radioactivity just below the Emory River was observed to be lower than that either above or below this stretch. At this location the TVA initiated construction activities at the Kingston Steam Plant and it is concluded that mud washed in from the construction area covered and shielded from the flounder much of the radioactive sediment that had previously been deposited.

Immediately upon passing out of the Clinch River into the main stem of Watts Bar Reservoir the radiation levels measured were much lower than in the Clinch River (see Fig. 4). This was to be expected because of the greater expanse over which the sediments were deposited. Counting rates dropped off progressively downstream, but here again as in the Clinch River the 1952 and 1953 levels were higher than the 1951 values. For several miles below each dam only background radiation was detected. This resulted from the absence of sediment in the turbulent reaches below the dams.

The highest intensities detected at various stations in the Clinch River are plotted on Fig. 5.

## Total Radioactive Sediment

Referring to Table II[11] it is seen that of the sediment in Chickamauga Reservoir only 23 percent is expected to have come from above Watts Bar Dam. Of that in Hales Bar only 29 percent originated above Chickamauga and by extending the calculation, only 6.7 percent from above Watts Bar Dam. Passing successive downstream dams the proportion of sediment in the various reservoirs originating above Watts Bar Dam would be Guntersville 2.0 percent, Wheeler 0.28 percent, Wilson 0.15 percent, Pickwick 0.06 percent, and Kentucky 0.01 percent. Since on a drainage area basis only 34 percent of the sediment entering Watts Bar Reservoir would be considered to have originated in the Clinch River basin, it may be seen that very small proportions of the sediment in the downstream reservoirs could be expected to have originated in the Clinch basin.

An effort has been made to approximate the amount of radioactive materials in the sediment. Since it was not possible to determine the depth of radioactive sediment or to obtain an undisturbed bottom sample for such a determination, it was necessary to make some assumptions. The first assumption was that the radiation detected by the flounder represented all the radioactivity in the sediment. The second was that such a measurement was characteristic of the sediment in certain portions of the cross-section as previously determined (see Presentation of Data). Both of these assumptions may be subject to great error.

Quantities proportional to the total radioactive sediment were calculated for all cross-sections measured in the river system by multiplying the average counting rate in each cross-section by the width of the stream at that cross-section. The values determined in this manner for the Clinch River embayment are plotted on Fig. 6. Whereas counting rates tend to level off as the mouth of the Clinch River is approached and to drop considerably after

Table II

Estimated Origin of Sediment

| Reservoir | Source of Sediment in Percent of Total | | |
|---|---|---|---|
| | From Principal Tributary Area | From Other Local Area | From Above Next Upstream Dam |
| Kentucky | 53 | 28 | 19 |
| Pickwick | 41 | 19 | 40 |
| Wilson | 32 | 16 | 52 |
| Wheeler | 73 | 13 | 14 |
| Guntersville | 36 | 34 | 30 |
| Hales Bar | 33 | 38 | 29 |
| Chickamauga | 49 | 28 | 23 |
| Watts Bar, less Clinch | 31 | 26 | 43 |
| Clinch Embayment | 60 | 40 | 0 |

The Principal Tributary Area in each case includes all tributaries of 200 square miles or larger.

reaching the main stem of Watts Bar Reservoir, the total accumulation continues to build up and the point of maximum accumulation of radioactive material (not shown on Fig. 6) seems to be about Mile 552.7 on the Tennessee River. Surprisingly enough, total accumulations in various cross-sections of Guntersville and Kentucky Reservoirs are almost as great as in Watts Bar. When considered with the length of river over which such accumulations were observed, it appeared that some other source of radioactive material must be responsible for this occurrence. Furthermore, during the 1952 survey counting rates in the Ohio River near the mouth of the Tennessee and in the mouth of the Cumberland River were found to be higher than those observed in the Tennessee River a short distance above its mouth.

## Radioactive Sediment of Geological Origin

There were no atomic energy installations on the Cumberland River to account for this radioactivity and no large research centers which might have accidentally lost such large quantities of radioactive materials. Chattanooga

Shale(7), a uranium bearing rock of the Devonian formation, outcrops extensively on the Cumberland Plateau (see Fig. 7) where it is for the most part flatbedded. Most of the outcroppings in the Tennessee Valley are tilted steeply and consequently result in less dissolution of radioactive constituents. While a narrow band of Chattanooga Shale parallels the Tennessee River above Chattanooga and narrow bands cross the Tennessee River at Chattanooga, there are few deposits of this shale outcropping in east Tennessee. In traveling downstream the first major outcrop is found between the Sequatchie River and the ridge which parallels it to the east. The Sequatchie River flows into the Tennessee River a short distance below Hales Bar Dam where for several miles turbulence would prevent extensive deposition. The counting rates in Guntersville Reservoir begin to increase downstream from Mile 390 and reach a level which cannot reasonably be expected to have been caused by materials originating at Oak Ridge since less than 1 percent of these sediments originated in the Clinch River basin. The only reasonable conclusion is that this results from erosion or leaching of radioactive substances from the Chattanooga Shale in the Sequatchie Valley and other local deposits.

In Wheeler Reservoir the rise in counting rate detected below the Elk River is undoubtedly the result of erosion of the outcropping of Chattanooga Shale in that section of north Alabama and south central Tennessee.

In Kentucky Lake the reach of the river in which the counting rate increases was not identified as well as might be desired, but there should be no doubt of its correlation with the Chattanooga Shale deposits in the Duck and Buffalo River areas.

Referring to Table I it is seen that the beta-gamma ratio ($\mu\mu$c/gm beta divided by $\mu\mu$c/g gamma) in the Clinch River mud was 1.1. In Watts Bar Reservoir at the mouth of the Clinch River it was 1.3 and a short distance farther downstream 1.9. In Guntersville Reservoir it was 2.4, Wheeler, 2.7, Pickwick 2.8, and Kentucky 3.0. By comparison the beta-gamma ratio from Chattanooga Shale was 3.3. Thus, the beta-gamma ratio from bottom sediments is seen to increase (approaching that of Chattanooga Shale) as the prevalence of shale in the watershed increases.

The counting rates observed in the Ohio River and in the mouth of the Cumberland River are believed to be attributable to the extensive outcroppings of Chattanooga Shale in that watershed.

## Possible Exposure to Radiation

The natural background exposure rate for man averages from 0.01 - 0.1 mr/hr[4] from cosmic and other natural radiation.(12) The Recommendations of the International Commission on Radiological Protection(13) are "in circumstances under which the whole body may be exposed over an indefinite period to X or gamma radiation of quantum energy less than 3 Mev the maximum permissible dose received by the surface of the body shall be 0.5r in any one week. This dose corresponds to 0.3 r/week measured in free air." Since the highest counting rates corresponded to 0.14 mr/hr the dose which might result from reclining on the mud continuously would amount to only 0.024 r/week or 8 percent of the maximum permissible dose.

While no one could be expected to lie on the bottom sediments continually, it is conceivable that the sediments might be dredged from the bottom and used in such a manner as to expose humans to the radiation. In this regard

4. Milliroentgens per hour.

an employee in a sand handling plant might be expected to be closer to the radioactive material for a longer period than any other person. If he were employed eight hours a day five days a week in such a place that he would receive 50 percent as much radiation as if he were lying directly on the lake bottom, his exposure for the week would amount to only 12 percent of that possible from lying on the bottom. Radiation would have to be increased to 104 times its 1952 level before such an individual would receive a maximum permissible dose. Assuming that the rate of annual accumulation as indicated by the increase observed from 1951 to 1952, is equal to half of the 1952 total, and might continue at a uniform rate in the future it would be 208 years (disregarding decay) before radiation would approach a level which might possibly result in significant exposures. When radioactive decay is taken into consideration it can be seen that such an exposure would never be encountered since the average half-life of the mixture of radioisotopes in the wastes would be much less than 33 years, which is the half-life of $Cs^{137}$, the longest lived isotope of those in the laboratory wastes for which analysis is routinely made. Thus, at this assumed rate of accumulation of radioactive sediments containing isotopes of half-lives comparable to the present known constituents the concentration would never reach a level which would create a human hazard from external exposure.

## CONCLUSIONS

It is believed that enough experience has been gained with various types of equipment to indicate that the procedures outlined herein are universally applicable to stream surveys.

It is believed that dispersion of radioactive sediment resulting from waste discharged from Oak Ridge does not extend downstream farther than Chickamauga Dam, or possibly Hales Bar Dam, to any measurable extent. The principal part of radioactive sediments found in Guntersville Reservoir and at points farther downstream are believed to have been derived from the erosion or leaching of Chattanooga Shale deposits.

No external exposure hazard has developed beyond the area of control as a result of the ORNL waste discharge program and the level of radiation would have to be over twelve times as great as the 1952 survey revealed before any hazard, however improbable, would even be possible. Since turbidity would normally be removed by conventional water treatment processes and the concentration of radioisotopes in solution is below the maximum permissible level for long time use, there is no ingestion hazard to humans resulting from waste disposal practices at the laboratory and the present water uses of the streams.

If the quantities and types of wastes discharged from ORNL were to continue at the same rate as during the year 1951-1952 and there were no other large sources of radioactive wastes developed in the same vicinity, the TVA lake system could store the resultant radioactive sediments indefinitely without presenting any external exposure hazard to humans.

On the other hand, from 1951 to 1952 to 1953 the calculated average concentration of radioactive substances in the Clinch River below the mouth of White Oak Creek rose from about 27 percent to 68 percent to 90 percent of the concentration which is acceptable in drinking water for lifetime use.[5] Should this trend be followed by the discharge of larger quantities of wastes of greater concentration of radioactivity, the potential internal hazard resulting from the use of the Clinch River as a source of drinking water for the gaseous diffusion plant at K-25 and the Kingston Steam Plant would have to be assessed.

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